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Software Applications for Runoff Hydrological Assessment

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Abstract. Natural Resource Conservation Service (NRCS) hydrology techniques are based upon unit hydrograph theory and the runoff curve number method of calculating direct runoff from the rainfall occurring over specified areas (National Engineering Handbook, Part 630, Hydrology, NEH-630.10 and 630.16). The Soil Conservation Service (SCS) and the Agricultural Research Service (ARS) in United States of America developed the supporting theory and verification studies for these since the 1940's and 1950's. In the beginning, all necessary computations were done by hand or by calculators and an analysis of a sizeable watershed typically took weeks or months. Since '80, they succeeded to develop computer programs to reduce the calculation time and allow analysis of complex sub-watershed systems. The software application has been developed all these years, adding new features and capabilities or modifications trying to be updated with the latest new computer technologies. The present paper presents three software applications developed for watershed hydrology, especially to calculate and analyze storm runoff volume, peak rate of discharge, and storage volumes for storm water management structures. The purpose of the analysis is to determine the application capabilities and limitations in order to use them in the specific Romanian conditions, with minimum modifications and adaptations.

Keywords: hydrology, water management, runoff, watershed comparative analysis

INTRODUCTION

In the frame of Severin Cazanescu's PhD thesis **"Studies and research regarding the use of information technology in the design process of the facilities for water excess control and prevention in rural area"**, guided by professor PhD Florin Maracineanu, the analysis of several models and software applications was had in view. These models and software applications could be used in the land reclamation projects (drainage, dewatering and irrigations) in Romania.

The main goal of the analysis was to find complex and advanced software applications that can be used in specific environment in Romania, with minimal modification or adjustment. The paper presents three such software applications, developed and used, on a large scale, in United States and Canada aiming to highlight their scope, capabilities and limitations and comparative analysis of the functions offered by these applications.

Many actual data from the project: **"Water excess mitigation in Ghelinta – Brates area, Covasna County"** has been used during the testing phase, in order to obtain accurate results.

MATERIALS AND METHODS

A briefly presentation of the analyzed software application has been performed, in order to be able to determine their capabilities and limitations for use in the specific Romanian conditions.

American Technical Release TR- 20 and Win TR-20 software application. The first version of the Technical release TR-20 was developed by Soil Conservation Service (SCS) in 1965, based on its researches and on Agricultural Research Service (ARS) researches, using the unit hydrograph theory and Runoff Curve Number method of calculating direct runoff from the rainfall occurring over specified areas. The mentioned theory and method are presented in the National Engineering Handbook, Part 630, Hydrology, NEH-630.10 and 630.16).

The technical Release TR-20 was subsequently revised in '80, when the first computing application was developed in Fortran 77. Nowadays, starting from the TR-20 model, an updated software application, running on Windows operating environment, named Win TR-20 has been released. The last version has dated since 2004, being currently improved.

Based on a continuous development for over 45 years, the Technical TR-20 led to the development of a modern software application Win TR-20, which allows the assessment and modeling of the rainfall-runoff and watershed routing calculations. WinTR20 represents the watershed as a system of sub-areas and reaches. The model assists in the hydrologic evaluation of flood events for use in the analysis of water resource projects. It can be used to analyze current watershed conditions as well as assess the impact of proposed changes (alternates) made within the watershed. The maximum size of the watershed is of 78000 hectares. Multiple storms (or rainfall frequencies) can be analyzed within one model run. The direct runoff is routed through channels and/or impoundments to the watershed outlet.

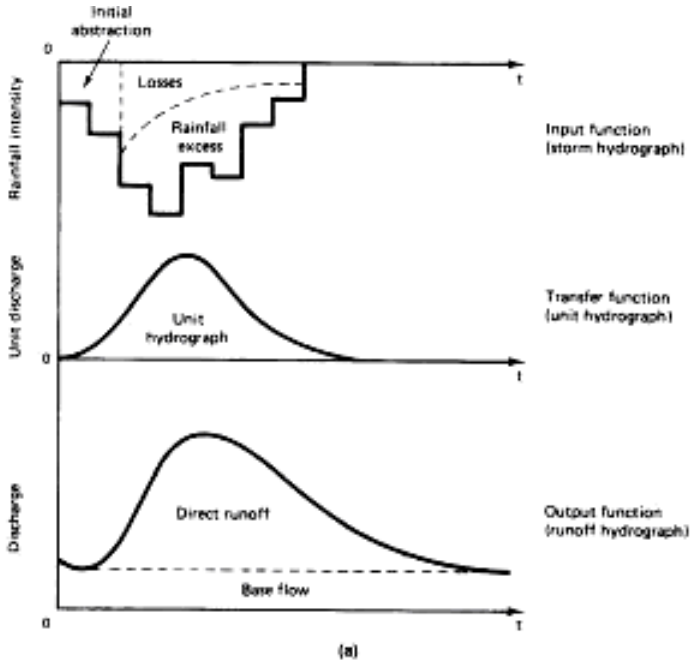

Fig. 1. Win TR-20 rainfall-runoff model (McCuen, 1998)

The unit hydrograph is the transfer function used by TR-20 to transform the rainfall excess into direct runoff. The rainfall hyetograph is convolved with the unit hydrograph to produce the direct runoff hydrograph. This process is explained in Figure 1.

In order to develop a simulated runoff hydrograph for each sub watershed, a minimum amount of information is required. The area, time of concentration, and curve number must be specified for each sub watershed. In order to route upstream hydrographs to downstream locations, a representative cross section is needed from which a stage-discharge-end area relationship can be produced.

Win TR-20 software application consists of more specialized modules, included into a single interface, easy to use (Win TR-20 User Guide, 2004). The most important modules are:

- Structures – calculates outflow from water impounding structures;
- Base flow – allows to process the flow rates resulted from rainfall hydrographs and to add the base flow to the storm hydrographs;
- Flow divert – allows the division of a reach hydrograph into two separate outflow paths;
- Runoff curve number (CN) - Calculates the CN for a designated sub-area based on detailed land use and hydrologic soil group (HSG) combination information which can be entered for the sub-area;
- Time of concentration (Tc)- Computes the time of concentration for a specific sub-area using the flow path information that have to be provided (flow lengths, slopes, Manning n, and cover type for sheet and shallow concentrated flow and flow length, slope, Manning n, flow end area and wetted perimeter or flow velocity for channel flow).

Based on the watershed characteristics provided and on the rainfall data, the application outputs are:

- Runoff amount;
- Discharge peak flow;
- Assessment of runoff hydrograph;

Technical release TR-55 and WinTR-55 software application. Technical Release TR – 55 is an American norm which includes simplified and fast computation procedures of the storm runoff volume, peak rate of discharge, hydrographs and storage volumes required for detention ponds. These procedures are applicable for small watersheds having maximum 6500 hectares.

The first version of TR-55 was issued in 1975, by the Soil Conservation Service SCS in United States of America and has been permanently updated, based on the researches, tests and experience acquired in time. The first revision was made in 1986, by adding three new types of rainfall distribution (SCS Type I, IA and III), versus the original model (SCS Type II) and a new velocity method of computing time of concentration was set, by splitting the time of concentration flow path into three distinct flow segments for sheet flow, shallow concentrated flow and channel flow.

WinTR-55 is the application version developed using a Windows interface and output post-processor. Data input philosophy was changed and the program was revised to use a hydrograph computational routine instead of generalized tables and graphs. As a result, the hydrograph generation capability of the software was greatly enhanced as the user can now flood route hydrographs through stream reaches and reservoirs.

The application is based on a model, developed for a single-event rainfall-runoff in small watershed (Win TR-55 User Guide, 2009). The model generates hydrographs from both urban and agricultural areas and at selected points along the stream system. Hydrographs are routed downstream through channels and/or reservoirs. Multiple sub-areas can be modeled within the watershed. A watershed consists of sub-areas (land areas) and reaches (major flow

paths in the watershed). For each sub-area, a hydrograph is generated based on land and climate characteristics.

The runoff modeling can be done in two ways:

- as channel reaches model, through which hydrographs are routed based on physical stream characteristics,

- as storage reaches, through which hydrographs are routed based on reservoir storage and outlet characteristics.

The runoff hydrographs collected and discharged are combined as needed to represent the accumulation of flow and of water movement from the upland areas down through the watershed reach network to the watershed outlet. The generated model for a watershed can consists of maximum 10 sub-areas and 10 reaches.

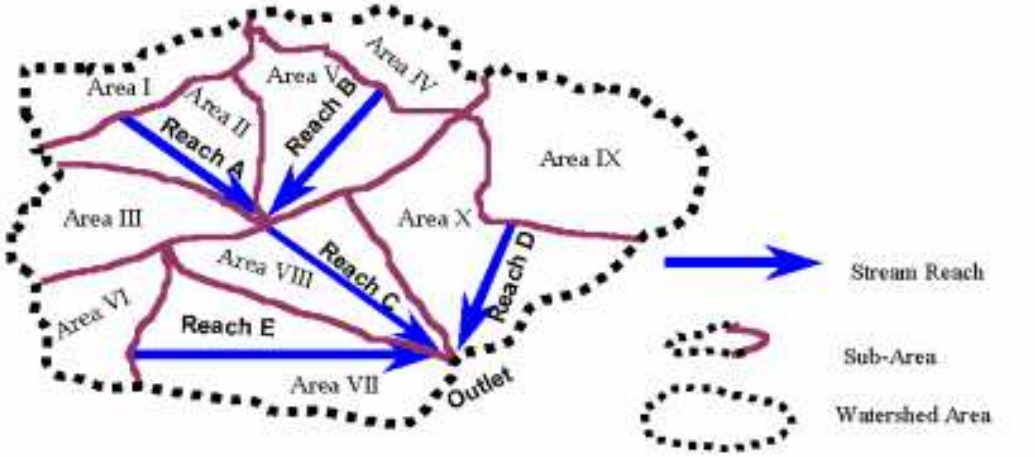

Fig. 2. Watershed computation scheme performed with Win TR 55

Win TR-55 application provides the following reports (Win TR-55 User Guide, 2009):

- peak hydrograph presentation and a listing of peak discharge and time by sub-area or reach identifier, for each storm evaluated;
- sub-area data table;
- reach summary table;
- sub-area time of concentration details
- sub-area land use and Curve Number details
- reach channel rating details
- structure output table and structure rating details.

Win TR–55 uses the Win TR–20 computational routine for generating, routing, and adding hydrographs. If the watershed exceeds 10 reaches or the channel or structural hydraulics require a complex rating relationship (for example, a principal spillway and an auxiliary spillway), another program should be used, such as Win TR–20 or HydroCAD.

HydroCAD

HydroCAD Storm Water Modeling System is a software application used to model the runoff generated by rainfalls. The first version was issued in 1986. The application combines Technical Release TR-20 and TR-55 and the generated model based on Santa Barbara hydrograph (SBUH), Soil Conservation Service (SCS) hydrograph and Natural Resources Conservation Service (NRCS) hydrograph, adding graphical functions and capabilities to use data basis and supplementary computational for hydraulic parameters (Fig. 3. and Fig. 4.).

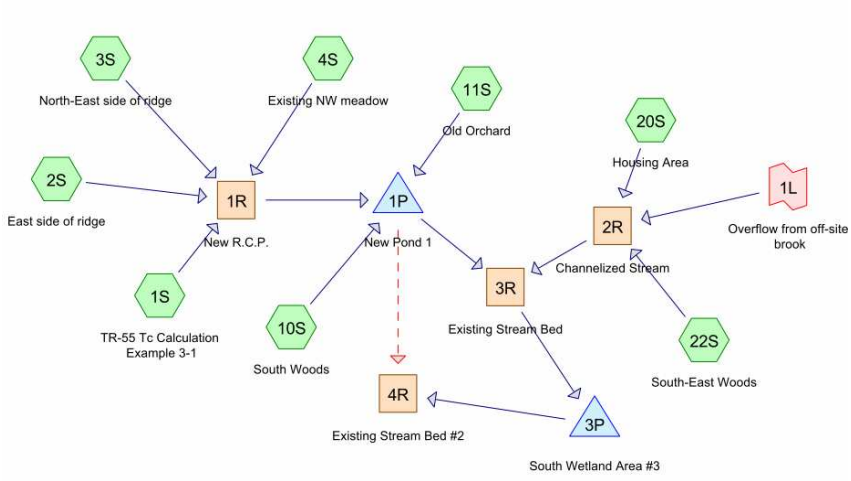

Fig. 3. Drainage system diagram

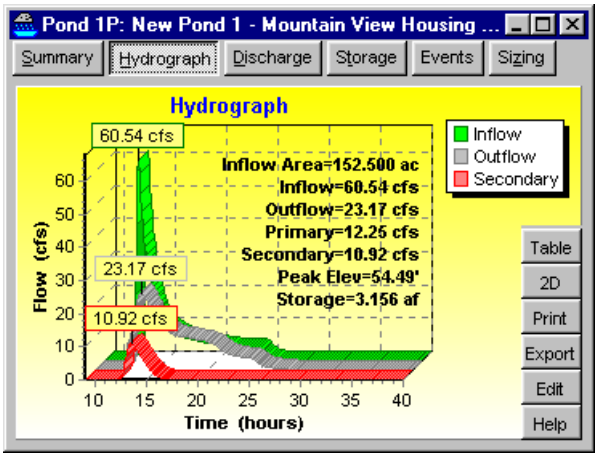

Fig. 4. Generated hydrograph by HydoCAD

The program performs a large series of computations, usually used for drainage systems design, computations including the followings (Stormwater Modeling System, Version 9.1, Owner's Manual, 2010):

- runoff hydrographs type SCS, NRCS and SBUH;
- use of the rational method to calculate the maximum rainfall flow with IDF(intensity-duration-frequency) curves;
- hydrograph routing through detention ponds/structures and pipes;
- calculation of detention ponds, including embedded storage, coupled with variable tail water;
- hydraulic computation of drainage pipes and channels;
- advanced pond storage calculations, including embedded storage;
- automated layout and modeling of underground storage chambers.
- land use analysis and pollutant loading calculation
- management and report of multiple rainfall types.

The last version of HydroCAD (HydroCAD 9.1) can be used together with Carlson Hydrology 2010, allowing to map soil groups, ground covers and sub-catchment boundaries, giving automatically all the sub-catchment necessary information to the HydroCAD model. The data are extracted from AutoCAD drawing, including AutoCAD Map or Civil 3D. If a

terrain model (TIN) is available, the time-of-concentration values can be automatically calculated using the Curve Number method and seamlessly transmitted to the HydroCAD model.

RESULTS AND DISCUSSION

Tab. 1

Summarized comparison of the three software applications results

	HydroCAD	**Win-TR-20**	**Win-TR-55**
Watershed minimum area	No restrictions	1 acre	No absolute minimum is included in the software. The user should carefully examine the results from sub-areas less than 1 acre.
Watershed maximum area	No restrictions	78000 hectares	6500 hectares
Runoff methodology used	SCS unit hydrograph procedure (unlimited points), Santa Barbara Urban Hydrograph, Rational Method	Unit hydrograph method	SCS unit hydrograph method based on Curve Number -CN
Rainfall type	Extensive rainfall library plus user-defined storms	NRCS Type I, Type I(48), Type IA, Type II, Type II(48), Type III, and Type NM (60-75) or user defined	NRCS Type I, IA, II, III, NM60, NM65, NM70, NM75, or user defined
Unit hydrograph	SCS or Delmarva U.H., plus user defined curves	SCS hydrograph is automated uploaded by the application, for other unit hydrographs , data need to be manually inserted	Dimensionless unit hydrograph – Velocity factor/ peak grade 484, or user defined having maximum 50 points
Curve number entry	Automatic curve number lookup and weighting, with adjustment for unconnected impervious areas	Automatic search or direct entry of curve number	Automatic curve number lookup and weighting, with adjustment for unconnected impervious areas.
Curve number limitations	No restrictions	30-100	30-100
Time of concentration calculation	All TR-55 methods plus common channel shapes, upland method, and CN method	2 calculation methods: NRCS method based on delay equation and NRCS velocity method	Calculates Tc for sheet, shallow concentrated and channel flow
Tc limitation	No restrictions	Tc > 0	0.1 hours < Tc < 10 hours
Tc precision	1/10 minutes or 1/600 hours	1/100 hours	Rounded to the nearest step
Subarea limitations	None	None	1-10
Runoff accuracy	Standard	Standard	Within +25% of TR-20
Reach routing	Muskingum-Cunge or Storage-indication method with optional routing delay (translation)	Muskingum-Cunge Method	Muskingum-Cunge Method

Reach hydraulics	Automatic calculation for common shapes or custom cross-sections	None. Requires entry of routing coefficients.	If the system has more than 10 reaches, channels or structures, needs a complex of estimation relations
Detention pond routing	Storage-indication method, dynamic storage-indication method, or simultaneous routing	Storage-indication	Storage-indication
Detention pond hydraulics	Automatic calculations for orifice, weir, culvert, etc, used alone or combined for outlet structures	Must be entered directly, no calculations provided	Detention pond defined by area, height, outlet structure dimensions and type and structure estimation formulas.
Detention pond sizing estimation	Using actual inflow hydrograph	Doesn't include this function	Assumes to define a pipe or to configure a weir. If none of the variants is accepted, another dimensioning method will be used, but not with the software application
Detention time	By plug-flow and center-of-mass methods	Not calculated	Not calculated
Pond storage calculations	Automatic calculation from pond dimensions or surface areas, plus direct entry	Direct entry only	There are 3 variants depending on pond input data for pond and outlet type
Underground storage	Automatic chamber layout and modeling, including embedded storage calculations	Requires external calculations	Requires external calculations
Flow diversions (split flows)	Automatic diversion of outflow from specified pond outlet(s)	Allows the diversion of the runoff hydrograph in two different reaches	Not available
Pollutant loading	Automatic land-use reporting and pollutant loading	None	None
Routing diagram	Interactive, on-screen, with labels and background image	None	None
Calculation procedure	Automatically calculated as required	"Batch mode" calculation of entire watershed	Manual initiation of each calculation
Unit system	English, Metric, or custom, plus split input/output units	Metric and English	Metric and English
Graphics capabilities	Full graphics to screen, printer, or file	Schematic watershed runoff view Hydrograph edit and printing	Hydrograph edit and printing
Reports	Automatic reports with headings, graphics, etc.	Reports with information regarding: peak discharge flow, drainage area; runoff amount; peak runoff occurrence time for each subarea.	Reports with input data; rainfall data; peak hydrograph and occurrence time, outlet structure data; drainage data; RNC time of concentration; tables with land use and soil curve number.
Storage data	Automatic by job name	Manual insert	Manual insert

An analyze of the technical similarities and differences between HydroCAD, Win TR-20 and Win TR-55 software applications have been performed and the obtained results are presented in Table 1. HydroCAD combines the most used functions of TR-20 and TR-55, having many other built-in hydraulics, graphics and automatic database and on-screen routing diagram.

CONCLUSIONS

Typical calculation and modeling existent in the three software applications can be used in Romania too, adapting the input data to the area specific features. Design activities which can be achieved with these computer programs include:

- design and sizing of drainage system components in order to control water excess;
- develop control strategies for minimizing the effects of water excess.

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